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WHITE POTATO STARCHES

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Conditions of paste formation required for making reproducible consistency measurements on domestic white potato starches are discussed. Several factors influencing the consistency of the paste, such as method of drying starch and the presence of water-soluble substances, have been studied. Consistency data are interpreted to yield information regarding the extent of degradation and/or the amount of soluble material present in starch samples. Twenty-four samples of potato starch produced by factories in the United States during the 1941-42 season have been examined by various chemical and physical tests. The consistency and particle-size measurements are discussed; the particle-size distribution of western potato starches is found to be different from that of Maine starches, but there is no relation between particle-size distribution and method of manufacture. Some conclusions are drawn regarding the influences of manufacturing methods and the water used in manufacture on the quality of starch.

POTATO starch has been produced in this country for more than 100 years. Many of the plants now in operation are old, and until recently little or no chemical control has been exercised over their manufacturing processes. In 1938 two new plants were established in Aroostook County, Maine, and others were modernized. In 1940 two starch plants were built in Idaho. Since 1938 a good-quality domestic potato starch has been available which is equal to that formerly imported from Holland and Germany (7).

Samples of starch produced in twenty-four plants during the 1941-42 season have been examined in this laboratory. Consistency measurements and analytical data obtained are presented, and their bearing on the quality of the starch is discussed.

MEASUREMENT OF CONSISTENCY

EFFECT OF RATE OF SHEAR. As others have reported previously, the apparent viscosity or consistency of a starch paste varies with the rate of shear. Thus in one experiment (2% paste at 70° C.), by varying the speed of rotation of the No. 3 spindle of a Brookfield viscometer from 6 to 60 r.p.m., the apparent viscosity was reduced from 2450 to 688 centipoises. In two other samples of potato starch paste, apparent viscosity was reduced from 3760 to 950 and from 3960 to 980 centipoises. A similar effect can be shown with the MacMichael viscometer by varying the speed of rotation of the cup and with the Stormer viscometer by varying the driving weight.

To secure comparable results, therefore, the consistencies of starch pastes should be measured at the same rate of shear and with the same instrument (6). This can be done readily with the Brookfield and MacMichael instruments. The Stormer viscometer can be used by varying the driving weight until an ar-

bitrarily chosen constant rate of shear—say 100 r.p.m.—is obtained, the viscosity being proportional to the driving weight. A capillary instrument, such as the Bingham and Green plastometer (5), can be used by varying the pressure to obtain a constant rate of flow.

EFFECT OF COOKING. Owing to its colloidal nature, the consistency of starch paste is influenced to a great extent by conditions of preparation. Accordingly, most workers specify exact methods for making the test paste. In spite of this, no matter how carefully directions are followed, it is difficult for different workers to check each other closely (9). This difficulty can largely be overcome by making the starch paste in an instrument in which heating and stirring are mechanically controlled. The consistency measurements should preferably be made in the same instrument in which the paste is made.

ONE-POINT vs. CONTINUOUS MEASUREMENT. Pierson (8), Caesar and Moore (4), and others have shown that a one-point viscosity determination is of little value in characterizing a sample of starch. Several instruments have been devised that permit consistency measurements to be made at several points or continuously during the cooking process. Among these are Caesar and Moore's consistometer (4), Barham, Wagoner, and Reed's rotating-cylinder viscometer (2), the cooking apparatus described by Pierson (8), and the Brabender Viscograph.

In the Brabender instrument (Figure 1), the material is placed in a cup which is rotated at constant speed; the drag on a series of rods suspended in the cup is measured by a torsion spring. The increase in temperature is held to a uniform rate by an automatic thermometer-controlled heating device. Consistency changes are recorded continuously on graph paper. Since the flow of material around the rods in the cup is turbulent rather than streamline, the results are not expressed in poises. The arbitrary viscosity units on the graph paper supplied with the instrument are used. The curves obtained with this instrument are readily reproducible.

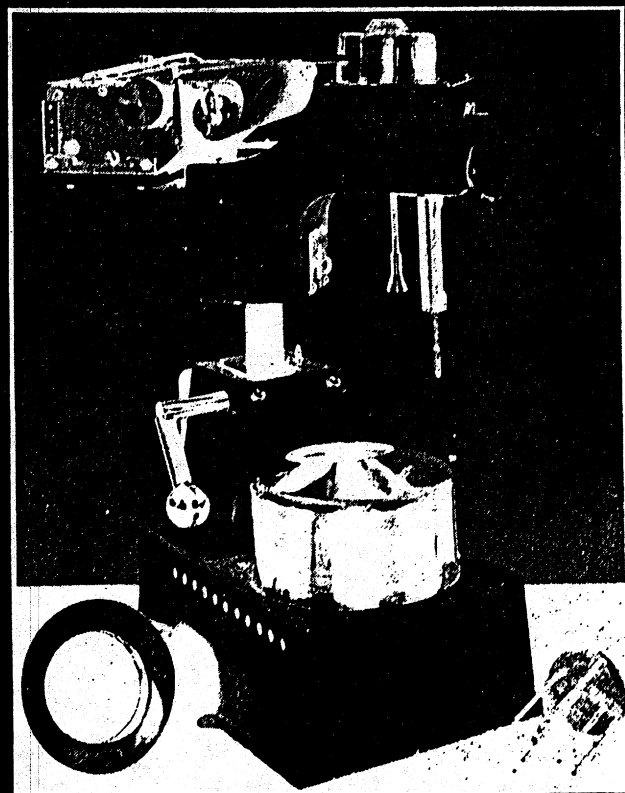


Figure 1. Brabender Viscograph (Disassembled)

TABLE I. EFFECT OF OVEN-DRYING^a ON MAXIMUM CONSISTENCY OF COMMERCIAL AIR-DRY POTATO STARCH

Drying Treatment	Hours	° C.	Sample 7		Sample 8		Sample 14	
			Residual moisture, % ^b	Max. consistency ^c	Residual moisture, %	Max. consistency	Residual moisture, %	Max. consistency
None (used as received)			15.0	690	15.8	830	15.6	800
Forced-draft	2	100	1.4	590	1.3	500	1.7	725
Gr.-convection	2	100	1.4	580	1.3	480	1.7	710
Gr.-convection	1.5	135	0.0	410	0.3	190	0.7	560
Vacuum	1	90	2.4	670	2.8	680	3.1	790

^a Samples roughly 1/2 inch deep in 9-cm. crystallizing dishes.

^b Determined by heating approximately 5-gram sample in 5-cm. weighing dish for 2 hours in gravity convection oven at 135° C.

^c In Brabender units.

The consistency-temperature curves (Figures 3 to 7, inclusive) were taken from the graphs made by the Brabender Viscograph. The curves, which have the same general shape as the corresponding original graphs, were transferred to rectangular coordinates and arranged to conform with general usage. Each determination was made with 500 grams of a 3.5% starch suspension.

FACTORS INFLUENCING CONSISTENCY

In the course of manufacturing and handling potato starch, a number of factors influence its consistency, such as the quality of water used, chemical treatment, drying, and storage. In this paper the effect of drying and the presence of water-soluble material are considered.

Drying. It is well known that heat degrades starch. In the absence of catalysts and at relatively low temperatures, the extensively degraded products known as dextrins or British gums are not produced, but it is reasonable to suppose that some change does take place. Therefore, the effect of drying starch by heat on the consistency of its paste was investigated. The results of some preliminary experiments are shown in Table I. It is evident from these data that drying starch by heat to below the air-dry moisture level at the temperatures used (90° to 135° C.) lowers its paste consistency in some cases to a considerable extent.

The effect of prolonged heating at 100° and 110° C. in a gravity convection oven on commercially dried starch is shown in Figure 2. Apparently the paste consistency continues to decrease

indefinitely or to a point where the material no longer gelatinizes. Perhaps a change similar to dextrinization is taking place, though at a very slow rate. An over-all picture of the consistency changes taking place at 110° C. with increasing time of exposure is shown in Figure 3; it also shows that the temperature at which the consistency peak occurs increases with continued heating until the peak disappears.

Since the dried starch as it came from the oven was used to obtain all the curves in Figure 3, another experiment was conducted to determine the effect

of the moisture content of starch on its paste consistency, independent of the effect produced by heating. A sample of the same starch was slurried with distilled water and de-watered on a Büchner funnel. The filter cake was divided in half. One half, A, was air-dried at room temperature; the other half, B, was dried overnight in a gravity convection oven at 100° C. and then allowed to remoisten in air at room temperature. Samples were taken from time to time from both portions, and moisture and consistency determination

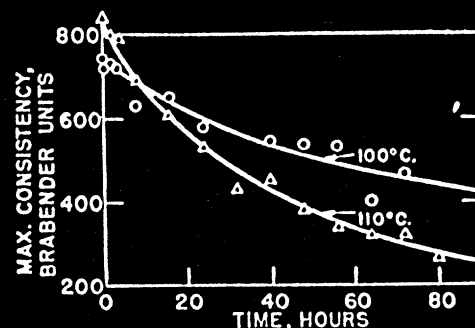


Figure 2. Effect of Prolonged Exposure to Dry Heat on Maximum Consistency of Potato Starch

(Curves were drawn by inspection.) Since identical samples were not used in both cases, the points of origin do not coincide.

TABLE II. SUMMARY OF DATA

Sample No.	% H ₂ O	% Ash	% Sol. in Cold H ₂ O	Acidity ^a	pH	Reflectance (MgO 100%)	Max. Consistency		Temp. of Peak Consistency, ° C.		Swelling Power, Ml.	Water Used in Mfg. ^c	Separating Equipment ^d
							Before washing	After washing	Before washing	After washing			
1	21.7	0.35	0.19	15.5	6.54	83.7	850	955	100°	95.5	85	W	WV
2	18.5	0.37	0.17	25.5	5.00	84.3	575	955	NP	99	60	S	WV
3	17.0	0.34	0.24	20.5	6.25	78.6	870	1040/	97	88	107	S	T
5 ^a	14.0	0.35	0.05	7.5	7.13	88.6	645 ^b	715 ^b	91	87	116	W	T
7	15.0	0.35	0.22	15.5	6.45	84.7	660	930	NP	98	71	S	WV
8	15.8	0.33	0.13	25.0	4.67	85.8	825	875	99	93.5	78	S	CV
9	16.5	0.34	0.06	<2.5	8.37	85.7	810	835	NP	100°	94	W	CV
10	16.7	0.38	0.10	12.0	6.50	82.4	800	915	95	90	195	S	T
11	17.9	0.31	0.15	5.5	7.53	89.4	745	760	92.5	92.5	155	S	T
12	19.0	0.37	0.24	24.0	5.26	83.2	690	965	NP	95	102	S	CV
13	21.6	0.37	0.12	20.5	6.40	84.5	870	1050/	97	88.5	110	S	WV
14	15.6	0.35	0.05	<2.5	8.28	91.1	800	860	94	91	112	W	T
15	6.0	0.36	0.18	19.0	6.17	81.0	590	705	NP	100°	80	S	CV
16	18.7	0.35	0.38	32.5	4.47	80.9	530	980	NP	92	113	S	WV
17	16.4	0.43	0.53	26.0	5.42	73.4	380	930	NP	100°	70	S	WV
18	20.7	0.33	0.23	18.5	6.35	86.2	710	855	NP	94.5	135	S	CV
19	13.6	0.36	0.29	23.5	5.75	80.4	440	630	NP	NP	89	S	WV
20	21.1	0.33	0.22	15.5	6.92	77.6	800	1040/	99	89	182	S	WV
21	13.3	0.33	0.24	24.0	5.52	84.1	450	710	NP	NP	94	S	WV
22	17.1	0.34	0.20	25.0	4.79	82.0	650	915	NP	95	149	S	CV
23	17.7	0.32	0.23	8.5	7.28	82.7	840	895	92	89	166
24	10.9	0.30	0.11	15.5	6.22	84.8	680	730	NP	100°	105
25	10.9	0.30	0.11	10.5	7.06	83.0	810	815	NP	99.5	112
26	10.7	0.35	0.43	19.0	6.20	82.7	230	360	NP	NP	78

Milliliters of 0.1 N. NaOH per 100 grams of starch.

NP indicates there was no peak in the consistency curve.

W indicates well water; S, surface water (creek, river, or pond). Blanks show no data were available.

WV indicates wooden vat; CV, concrete vat; T, tables. Blanks show no data were available.

^a Peak appeared to be forming at boiling point.

^b Estimated above 1000.

^c Since samples 4 and 6 were wet and obviously spoiled, they were not examined.

^d 2 1/2% suspension; 3 1/4% beyond capacity of apparatus as used for other samples.

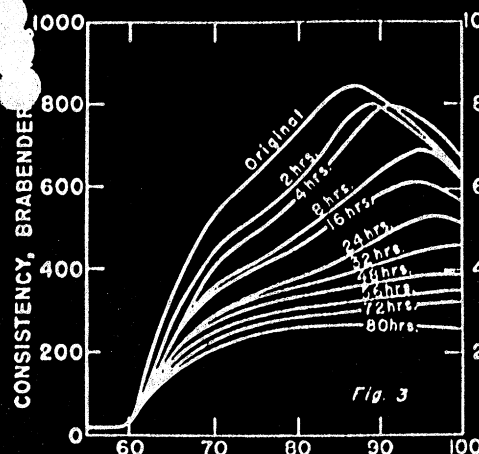


Fig. 3

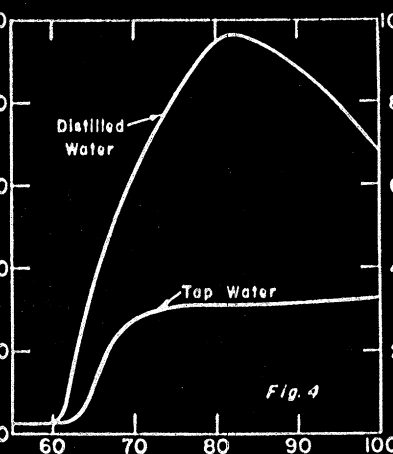


Fig. 4

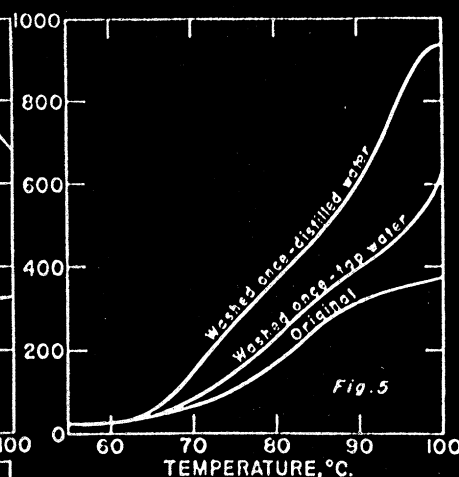


Fig. 5

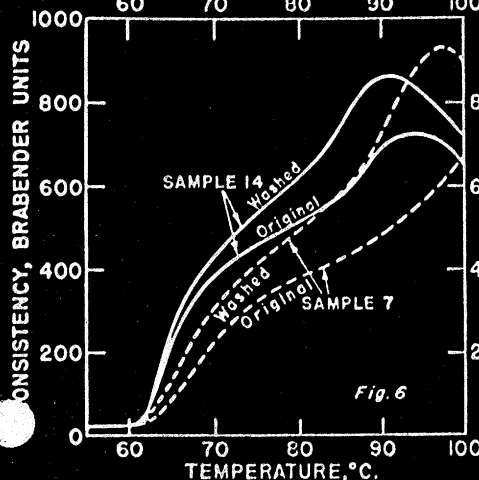


Fig. 6

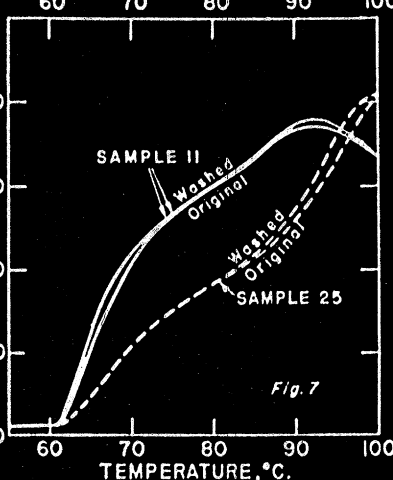


Fig. 7

Figure 3. Effect of Time of Exposure to Dry Heat (110° C.) on Consistency Curve of Potato Starch

Figure 4. Effect of Water Used on Consistency of Potato Starch Paste

Figure 5. Effect of Washing on Consistency of Potato Starch (Sample 17)

Figure 6. Effect of Washing on Consistency of Potato Starch
Sample 7, broken line; sample 14, solid line.

Figure 7. Effect of Washing on Consistency of Potato Starch
Sample 11, solid line; sample 25, broken line.

made. The peak consistencies of the samples from portion A ranged from 740 to 780; the maximum consistencies (there were no peaks in the curves) of the samples from portion B ranged from 460 to 500. After both were exposed to air for 32 hours, A had a moisture content of 13.3% and a peak consistency of 770, while B had a moisture content of 13.4% and a maximum consistency of 480. Therefore, it appears that the previously noted decreases in consistency were due to the action of the heat and not to the moisture content of the starch.

Another result of oven drying considered here was the formation of water-soluble material and its possible effect on the paste consistency. To test this possibility, a sample from portion B was washed several times by decantation with distilled water and air-dried; then its consistency was measured. The maximum consistency of this sample was 475, which lies within the range of the unwashed samples from portion B.

Although drying starch to nearly zero moisture content causes considerable lowering of paste consistency, the oven drying of wet starch to the air-dry moisture range, at temperatures below 90° C., does not result in such an effect. Samples of wet starch from two Maine factories were dried in quarter-inch and half-inch layers in gravity-convection and forced-draft ovens at 60° to 80° C. for 1 to 5 hours. The moisture content was thereby reduced from 40 to 16% without noticeable change in consistency.

WATER-SOLUBLE MATERIAL. It is generally known that the presence of small amounts of electrolytes and perhaps other soluble material influences the consistency of starch pastes. This effect is clearly demonstrated in Figure 4, where consistency-temperature curves are given for two pastes made from the same starch, one using distilled water and the other using tap water. In the latter case the soluble material of the tap water was added

to the starch paste. All commercial starches contain some soluble material, part of which might originate in the drying process. It was shown above, however, that the water-soluble material formed in starch on heating does not influence its paste consistency. The effect on consistency, therefore, is caused by solubles introduced by the water used in processing. The effect of soluble material on consistency can be measured by making consistency determinations on a sample before and after it is washed with distilled water. Our experiments have shown that one washing is sufficient; subsequent washings did not cause any appreciable change in the consistency curve.

Keeping in mind the effects of heat degradation and contamination with electrolytes on the consistency of starch pastes, the result produced by washing should give some indication of the causes of low consistency. The foregoing discussion has brought out that a clean, undegraded sample of potato starch should have a high peak consistency and should exhibit this peak at a temperature below the boiling point of the paste. The less the heat degradation, the lower the temperature of the consistency peak. If the original sample has no consistency peak and a definite peak appears after washing, it is evident that the sample contained water-soluble impurities that affected the viscosity. If, on the other hand, no peak appears even after washing with distilled water, it is a good indication that the sample itself was degraded during manufacture or handling. If the original sample has a consistency peak and washing with distilled water causes this peak to occur at a lower temperature, it may be inferred that the original sample is slightly contaminated with water-soluble impurities that lower its consistency.

All washing was done by decantation. Thirty grams of air-dry starch were stirred with 500 ml. of water in a 600-ml. beaker,

TABLE III. AVERAGE PARTICLE-SIZE DISTRIBUTION OF MAINE AND WESTERN POTATO STARCHES^a

Particle Size Range, Microns	Average %		Particle Size Range, Microns	Average %	
	Maine	Western		Maine	Western
0-10	4.8	2.2	40-50	2.7	5.2
10-20	36.4	25.6	50-60	1.5	3.2
20-30	41.0	41.4	60-70	1.0	1.8
30-40	10.0	18.8	70-80	0.5	1.3

^a Values obtained by interpolation from Figure 8.

the starch was allowed to settle, and the supernatant liquor was poured off. After the final washing, the sample was slurried with 100 ml. of water and dewatered on a Büchner funnel (13.5 cm.). Air at room temperature was drawn through the filter cake for about 2 hours. The moisture content after this treatment was 13 to 14%.

The factors influencing the consistency of potato starch pastes are complex. Naturally, cold-water-soluble material and degradation by heat are not the only causes for differences in consistency among various samples. Thus, while sample 25 (Figure 7) is degraded according to the criterion presented here, its maximum consistency is higher than the peak consistency of sample 11 (Figure 7) which, by the same criterion, is undegraded. For this reason it should be emphasized that the important considerations in interpreting paste consistency data are the appearance of a peak in the consistency-temperature curve and the changes in this curve after the sample is washed, rather than the magnitude of the peak or maximum consistency.

EXAMINATION OF 1941-42 STARCHES

Samples of domestic potato starch from twenty-four plants operating during the 1941-42 season were examined. It is realized that one sample cannot be accepted as representative of a manufacturer's entire production for a season. Since all the samples from the principal producing area (Aroostook County, Maine) were collected at the same time, however, it is reasonable to expect that most of the factors influencing the quality of this starch, other than the conditions prevailing within the factories, were uniform. (The weather and soil types in various parts of the potato-growing area are fairly uniform, but the varietal factors and cultural practices differ somewhat. Consequently, the preceding statement is not strictly correct, but that it is justifiable is borne out by subsequent results.) Therefore it may be assumed that differences among the various samples reflect manufacturing conditions. The following determinations were made; all weights of starch are given on the dry-weight basis:

MOISTURE was determined as the percentage loss in weight of a 5-gram sample (approximate) when heated for 2 hours at 135° C. in a gravity-convection oven.

ASH was determined by igniting about 3 grams of dried starch in a muffle furnace at about 600° C. until the ash was just fused.

SOLUBLE MATERIAL. Cold-water solubles content was determined by shaking 25 grams of starch for 10 minutes at room temperature with sufficient distilled water to make a total weight of 175 grams. This was followed by centrifuging, decanting through a filter, evaporating a 50-ml. portion of the filtrate to dryness, and heating the residue to constant weight at 100° C. The amount of soluble material per 100 grams of starch was calculated.

ACIDITY was determined by titrating a suspension of 20 grams of starch in 100 ml. of distilled water with 0.1 *N* sodium hydroxide to a 30-second phenolphthalein end point. Owing to difficulty in reading the end point, the results were not precisely reproducible. Acidity was expressed as milliliters of 0.1 *N* sodium hydroxide per 100 grams of starch. The pH determinations were made with a Beckman pH meter, using suspensions of 1 gram of starch in distilled water to make a total weight of 6 grams.

CONSISTENCY. Distilled water was used in preparing the starch paste. Two determinations were made on each sample with the Brabender instrument as described above. A consistency curve was made for the original sample (as received)

and another after it was washed with distilled water (Figures 5, 6, and 7). The maximum consistency in arbitrary units and the temperature at which the consistency peak, if any, occurred are recorded in Table II for both determinations. The point at which the consistency curve bends away from the temperature axis (Figures 3 to 7) is the gelatinization temperature of the sample. There was little variation in the gelatinization temperatures; the range was roughly 60° to 65° C., the higher temperatures being rather indefinite because of slow gelatinization.

REFLECTANCE. Degree of whiteness was measured as the amount of light (wave length, 450 mμ) reflected relative to magnesium oxide (MgO = 100%) by a smooth surface of each sample. All samples were measured as received except that pearl starch was first powdered in a glass mortar.

SWELLING POWER was determined by Ripperton's method (9, 10), using 1.2 grams of starch and a total of 300 ml. of water in a 500-ml. cylinder. Examination of the data reveals no correlation with any other property measured.

PARTICLE SIZE distribution was measured for all the samples. The A.S.T.M. hydrometer method (1) was used. The samples were dispersed in water with a Waring Blender. Table III gives data on the particle-size distribution of Maine and western starches. These data are presented as distribution curves in Figure 8.

In addition to these data, information was obtained concerning the manufacturing methods and water used in the Maine starch factories. Figure 5 shows the effect of washing on a sample of starch of apparently inferior quality. Even washing with tap water increased the consistency over that of the original sample. In the curve for the portion washed with distilled water, a peak appears to be forming at the boiling point of the paste. In Figure 6 a definite peak appears in the curve for the washed portion of sample 7, whereas the curve for the original sample has no peak; with sample 14, the peak for the washed portion occurs at a lower temperature than the peak for the original sample. In Figure 7, however, washing the samples with distilled water caused little change in the consistency-temperature curves.

Interpreted in the light of preceding experiments, the implications of Figures 5, 6, and 7 are as follows: Sample 17 (Figure 5) contains water-soluble impurities and is somewhat degraded. Sample 7 (Figure 6) contains soluble material and is probably degraded less than sample 17. Sample 14 (Figure 6) is relatively undegraded, though it contains some soluble material. Sample 25 (Figure 7) is somewhat degraded, and has a low content of soluble material. Sample 11 (Figure 7) neither contains much soluble material nor is degraded to any great extent.

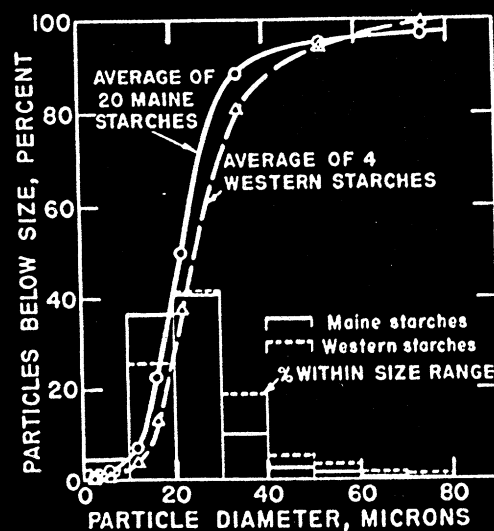


Figure 8. Particle Size Distribution Curves Showing Differences between 1941-42 Maine and Western Potato Starches

Bars indicate % within successive size ranges.

USE OF DATA IN EVALUATING STARCH

Tests other than consistency measurements are important in evaluating a starch sample. As Table II shows, the ash content of white potato starch is fairly uniform within a rather narrow range (roughly 0.30 to 0.37%). An ash content substantially higher than 0.37% might indicate the presence of extraneous nonvolatile material, such as soil particles. The presence of an excessive amount of cold-water soluble material might lead us to suspect that in some cases the starch was degraded. Excessive acidity, especially if accompanied by a sour or musty odor, would be likely to indicate bacterial degradation. Low pH might have similar implications. For some uses, degree of whiteness in itself is an important consideration, aside from the fact that discoloration or specks of dirt would indicate spoilage or contamination. A moisture content of about 12 to 18% is desirable for shipping and storing.

To summarize, a sample of average-quality potato starch should have an ash content of about 0.35%, low acidity, a pH near the neutrality point, high reflectance, and a paste consistency-temperature curve in which a peak occurs below the boiling point and which remains substantially unchanged when the sample is washed with distilled water.

Since many variables influence the quality of potato starch, it is difficult to evaluate the product adequately. In practice, starch should be evaluated for the properties required for a specific application.

WATER AND MANUFACTURING METHODS

The data in Table II show that, when well water is used for washing the starch, further washing with distilled water produces relatively little increase in paste consistency or decrease in temperature of peak consistency. Starch made with surface water generally appears to be of poorer quality than that made with well water. Two of the highest grade samples (5 and 14) were made with well water, and tabling was used for starch separation. It is also apparent that in the batch vat process better starch is made in concrete vats than in wooden ones. These conclusions are brought out by the data in Table IV.

TABLE IV. AVERAGE INCREASE IN MAXIMUM CONSISTENCY PRODUCED BY WASHING VARIOUS CLASSES OF SAMPLES

Class of Starch	No. of Samples Examined	Average Increase in Maximum Consistency
Western ^a	4	60
Washed with well water	4	65
Purified by tabling	5	86
Purified by settling in concrete vats	6	146
All samples	24	174
Maine	20	197
Washed with surface water	16	229
Purified by settling in wooden vats	9	292

^a No data on water or purification method available.

Since the number of samples examined was limited, it was not possible to take into account the interaction of the different factors involved. Statistical treatment could have been employed had the number of samples been sufficiently large. It should be remembered, too, that samples may show only a small consistency increase on washing and still be badly degraded; hence, the data in Table IV relate to contamination only by water-soluble impurities affecting consistency, no consideration being given to inherent degradation.

No information was available as to the drying conditions used in the various factories. It is thought that some of the samples which showed no peak in the consistency curve, even after washing, may have been degraded by bacterial action accelerated by the conditions of drying or storing.

While better starch is produced by tabling than by vat settling, no provision is made in either method for the removal of im-

purities heavier than starch, such as soil particles; even the best samples examined contained some heavy particles that settled faster than the starch granules. Dirt particles were always noticed at the bottom of the beaker in the washing experiments.

Thurber and Paine (11) proposed a method of starch purification that would permit removal of dirt particles of greater density than the starch granules and too small to be removed by screening, although they do not point out this advantage. This method of purification, which employs continuously operated settling columns or hydroseparators, has other advantages that should make its use valuable in the production of white potato starch. As Thurber and Paine pointed out, the advantages are continuous and practically automatic operation, relatively small requirements for floor space (about one-third that required for tables), and elimination of much hand labor. This process, however, is not used for potato starch purification in this country, so far as is known.

PARTICLE-SIZE DISTRIBUTION

It was thought there might be a relation between particle-size distribution and method of purification. The yields by the old batch vat process are only 50 to 70% of the available starch, whereas the yield of a modern factory using the tabling process is more than 90% (3). Since the surface of the settled layer is scraped in the vat process, it was reasoned that most of the starch thus lost would be in the small particle-size ranges.

This suspected relation was investigated as follows: An average cumulative particle-size distribution curve was constructed by averaging the percentage under-size for all the samples at each size at which a measurement was made and plotting these average values. Similar average curves were then constructed for the tabled samples, for the samples settled in concrete vats, and for the samples settled in wooden vats. The curves thus obtained were practically congruent, indicating that the method of purification had no bearing on particle-size distribution.

A similar comparison was made between starch produced in Maine (samples 1 to 22, inclusive) and that produced in the western states of Idaho, Minnesota, and Oregon (samples 23 to 26, inclusive). In this case there were noticeable differences, as Figure 8 shows. The values in Table III and the bar graphs in Figure 8 were obtained by interpolation from the distribution curves.

ACKNOWLEDGMENT

The reflectance determinations were made by B. A. Brice and R. M. Chapman of the Analytical and Physical Chemistry Division of this laboratory. Information concerning the water and manufacturing methods in the Maine factories was supplied by courtesy of the Food Distribution Administration. The cooperation of the potato starch manufacturers in submitting samples is appreciated.

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PRESENTED before the Division of Sugar Chemistry and Technology at the 106th Meeting of the AMERICAN CHEMICAL SOCIETY, Pittsburgh, Pa.